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Abstract

Different phenomenological approaches for Λ and $\overline{\Lambda}$ polarization in polarized semi-inclusive deep inelastic scattering and electron-positron annihilation at Z^0 pole are considered. Current and future experiments will soon provide accurate enough data to study spin phenomena in these reactions and distinguish between various models.

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The self-analysing properties of the $\Lambda(\overline{\Lambda})$ make this particle particularly suited for spin physics. Non-trivial *negative* longitudinal polarization of Λ's produced in the target fragmentation region of the deep-inelastic $\bar{\nu}$ scattering, measured with respect to the direction of the momentum transfer from the beam, has been observed in WA59 experiments [1]. These data can be interpreted in a simple way [2] by using the model of polarized intrinsic strangeness in polarized nucleon [3]. According to this model a valence quark core with (essentially) the naïve quark model spin content may be accompanied by a spin–triplet $\mathsf{s}\bar{\mathsf{s}}$ pair in which the $\bar{\mathsf{s}}$ antiquark is supposed to be negatively polarized, motivated by chiral dynamics, and likewise the s quark, motivated by ${}^3P_0$ quark condensation in the vacuum.

The essence of our argument [2] is that the right-handed polarization of the $\bar{\nu}$ beam is transferred to the hadrons via polarized W^--exchange, which selects preferentially one *longitudinal* polarization state of the nucleon target. Specifically, in most interactions the $\bar{\nu}$-induced W removes a *positively*-polarized u quark from the nucleon target, as seen in Fig. 1.

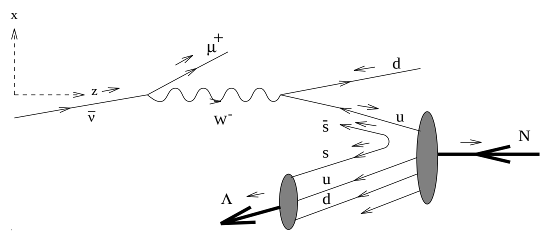


Figure 1: *Dominant diagram for Λ production in the target fragmentation region due to scattering on a valence* u *quark. Each small arrow represent the longitudinal polarization of the corresponding particle.*

In the naïve quark-parton model of deep-inelastic ν or $\bar{\nu}$ scattering, the net longitudinal polarization of a remnant s quark , P_s, is given by

$$P_s = \frac{\sum_q c_{s\,q} N_q - \sum_{\bar{q}} c_{s\,\bar{q}} N_{\bar{q}}}{N_{tot}}, \tag{1}$$

where $c_{s\,q}$ is the remnant s quark spin-correlation coefficient with the struck quark q, N_q ($N_{\bar{q}}$) is the total number of events selected in which a quark (antiquark) is struck, and $N_{tot} = N_q + N_{\bar{q}}$ is the total number of events selected. According to the polarized strangeness model, the polarization of the remnant s quark is 100% *anticorrelated* with that of the valence quark, and 100% *correlated* with that of struck sea $\bar{\mathsf{s}}$ antiquark (see Fig. 2):

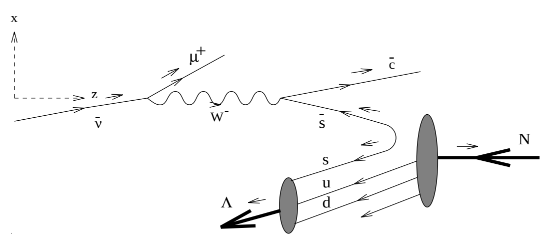


Figure 2: *Diagram for Λ production in a $\bar{\nu}\,N$ event due to W interaction with a* $\bar{\mathsf{s}}$ *quark from the sea. As in Fig. 1, the small arrows represent longitudinal polarizations.*

$$\begin{aligned} c_{s\,u_{val}} &= c_{s\,d_{val}} = -1, \\ c_{s\,\bar{q}_{sea}} &= \delta_{\bar{s},\bar{q}}. \end{aligned} \tag{2}$$

In the simple quark model the polarization of a directly-produced Λ is the same as that of the remnant s quark. However, final-state Λ's may also be produced indirectly via the decays of heavier hyperon resonances, which tends to dilute the Λ polarization by a factor we denote by D_F. Thus the final-state longitudinal Λ polarization is

$$P_\Lambda = D_F P_s, \tag{3}$$

The fraction of Λ's produced indirectly may vary with the kinematical conditions, e.g., it may be higher when the invariant mass of the produced hadron system is larger.

We have used the Lund Monte Carlo program LEPTO to obtain numerical results. In the Table 1 our results for the polarization P_s of the remnant s quark in various ranges of Bjorken x, together with the corresponding values of P_Λ measured in WA59 experiment. We also tabulate the corresponding values of D_F inferred from our calculated values of P_s and the measured values of P_Λ.

x range	$0 < x < 1$	$0 < x < 0.2$	$0.2 < x < 1$
P_Λ in WA59 experiment	-0.63 ± 0.13	-0.46 ± 0.19	-0.85 ± 0.19
P_s in our model	-0.86	-0.84	-0.94
Dilution factor D_F	0.73 ± 0.15	0.55 ± 0.23	0.90 ± 0.20

Table 1: Λ *polarization in the target fragmentation region* ($x_F < 0$).

The similar value and sign of Λ polarization is expected also for the ν-beam.

It is interesting to contrast the above predictions with the expectation for the meson cloud model of DIS [4]. In such a model the Λ polarisation in the target fragmentation region is expected to be zero for unpolarized target (in contradiction with WA59 data) and very strongly anticorrelated with the target polarization. In the similar light-cone meson-baryon fluctuation model [5] one expect the negative polarization for the produced Λ and zero (or slightly positive) for the produced $\overline{\Lambda}$ whereas in our approach both polarization are expected to be negative.

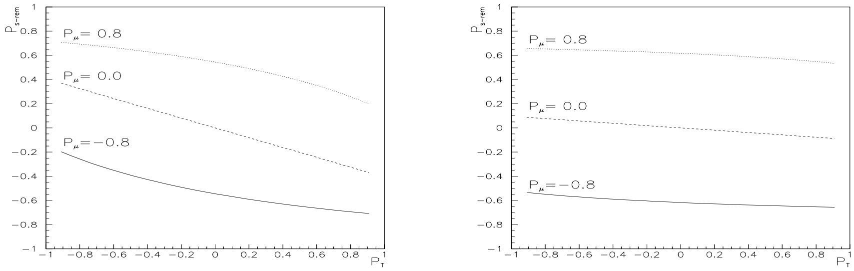
Next we apply our model to predict the polarization of Λ's produced in the target fragmentation region in the deep-inelastic scattering of polarized muons (electrons) on both unpolarized and polarized nucleon targets. It is easy to find the following expression for the polarization of the remnant s quark

$$P_{s_{rem}} = \frac{\sum_q e_q^2[P_T \Delta q(x) - P_B D(y) q(x)] c_{s\,q}}{\sum_q e_q^2[q(x) - P_B P_T D(y) \Delta q(x)]}, \tag{4}$$

where P_B and P_T are the beam and target longitudinal polarizations, e_q is the quark charge, $q(x)$ and $\Delta q(x)$ are the unpolarized and polarized quark distribution functions, and $D(y) = [1-(1-y)^2]/[1+(1-y)^2]$.

The results of our calculations for a μ beam with the longitudinal polarization $P_\mu = -0.8$ are shown in Fig. 6, together with the cases $P_\mu = 0$ and 0.8.

The produced Λ polarization is given by equation (3). We concluded from our analysis of the WA59 data that in the valence-quark region the fragmentation dilution factor



(a) *Proton target* (b) *Ammonia target*

Figure 3: *Polarization of remnant* s *quark for deep-inelastic* μ *scattering, as a function of the target polarization* P_T *for different values of the beam polarization* P_μ*. a) for a proton target, b)for an ammonia target. We assume* E_μ*=190 GeV and the following cuts were applied:* $-0.3 < x_F < 0$, $x > 0.15$, $0.5 < y < 0.9$.

$D_F \gtrsim 0.7$. Therefore, we expect large polarization effects also for Λ production in the target fragmentation region in deep-inelastic $\mu\, N$ scattering.

Complementary nonperturbative phenomenon to polarized parton distribution in the polarized nucleon is the polarization transfer in the quark fragmentation process. I will present the results of our calculations [6, 7] for different phenomenological spin transfer mechanisms for the Λ and $\bar{\Lambda}$ longitudinal polarization in various lepton induced processes.

The leading twist unpolarized ($D_q^\Lambda(z)$) and polarized ($\Delta D_q^\Lambda(z)$) quark fragmentation functions to a Λ hyperon are defined as:

$$
\begin{aligned}
D_q^\Lambda(z) &= D_q^{+\,\Lambda}(z) + D_q^{-\,\Lambda}(z) && (5)\\
\Delta D_q^\Lambda(z) &= D_q^{+\,\Lambda}(z) - D_q^{-\,\Lambda}(z), && (6)
\end{aligned}
$$

where $D_q^{+\,\Lambda}(z)$ ($D_q^{-\,\Lambda}(z)$) is the spin dependent quark fragmentation functions for the Λ spin parallel (antiparallel) to that of the initial quark q, and z is the quark energy fraction carried by the Λ hyperon.

We parametrize the polarized quark fragmentation functions as

$$\Delta D_q^\Lambda(z) = C_q^\Lambda(z) \cdot D_q^\Lambda(z), \tag{7}$$

where $C_q^\Lambda(z)$ are the spin transfer coefficients.

Two different descriptions of the spin transfer mechanism in the quark fragmentation to a $\Lambda/\overline{\Lambda}$ hyperon are considered. The first one is based on the non-relativistic quark model SU(6) wave functions, where the Λ spin is carried only by its constituent s quark. Therefore, the polarization of directly produced Λ's is determined by that of the s quark only, while Λ's coming from decays of heavier hyperons inherit a fraction of the parent's polarization, which might originate also from other quark flavors (namely u and d). In this scheme the spin transfer is discussed in terms of *constituent quarks.* Table 2 shows the spin transfer coefficients C_q^Λ for this case [8, 9]. A particular case is given by a simpler assumption that the Λ hyperon gets its polarization from s quarks only. In the following we will refer to the former description as *BGH* (*for* Bigi, Gustafson, and Häkkinen) and the latter as *NQM* (*for* naïve quark model).

The second approach is based on the g_1^Λ *sum rule* for the first moment of the polarized quark distribution functions in a polarized Λ hyperon, which was derived by Burkardt

Λ's parent	C_u^Λ	C_d^Λ	C_s^Λ	$C_{\bar{q}}^\Lambda$
Quark	0	0	+1	0
Σ^0	−2/9	−2/9	+1/9	0
$\Sigma(1385)$	+5/9	+5/9	+5/9	0
Ξ	−0.3	−0.3	+0.6	0

Table 2: *Spin transfer coefficients according to non-relativistic SU(6) quark model.*

	C_u^Λ	C_d^Λ	C_s^Λ	$C_{\bar{q}}^\Lambda$
BJ-I	−0.20	−0.20	+0.60	0.0
BJ-II	−0.14	−0.14	+0.66	−0.06

Table 3: *Spin transfer coefficients according to the Burkardt-Jaffe g_1^Λ sum rule.*

and Jaffe [10] in the same fashion as for the proton one (g_1^{p}). We assume that the spin transfer from a polarized quark q to a Λ is proportional to the Λ spin carried by that flavor, *i.e.* to g_1^Λ. Table 3 contains the spin transfer coefficients C_q^Λ, which were evaluated using the experimental values for g_1^{p}. Two cases are considered [11]: in the first one only valence quarks are polarized; in the second case also sea quarks and antiquarks contribute to the Λ spin. In the following we will refer to the first one as *BJ-I* and the second one as *BJ-II*.

In the g_1^Λ *sum rule* scheme a negative spin transfer from u and d quarks to a Λ hyperon is predicted. This effect can be understood qualitatively even if the spin of the Λ is determined by its constituent s quark only: in some cases the fragmenting u or d quark will become a sea quark of the constituent s quark, and the spin of the constituent s quark will be anti-correlated to the spin of the fragmenting quark [3, 2]. Another possibility occurs when the Λ is produced as a second rank particle in the fragmentation of a u or d quark. If the first rank particle was a pseudoscalar strange meson, then the spin of the $\bar{\mathsf{s}}$ antiquark has to be opposite to that of the u (d) quark, and since the $\mathsf{s}\bar{\mathsf{s}}$ pair created from the vacuum in the string breaking is assumed to be in a $^3P_0$ state, the s quark is also oppositely polarized to the u or d quark. This last mechanism of the spin transfer can be checked by measuring the Λ polarization for a sample of events containing fast K mesons.

For charged lepton DIS the fragmenting quark longitudinal polarization is given by the simple parton model expression [7, 2]

$$P_{q'}\,(x,y) = \frac{P_B D(y) q(x) + P_T \Delta q(x)}{q(x) + P_B D(y) P_T \Delta q(x)}. \tag{8}$$

For neutrino scattering the flavor changing charged current weak interaction selects left-handed quarks (right-handed antiquarks), giving 100 % polarized fragmenting quarks. The Standard Model predicts a high degree of longitudinal polarizations for quarks and antiquarks produced in Z^0 decays: $P_s = P_d = -0.91,\ P_u = P_c = -0.67$.

The results [6] for longitudinal $\Lambda/\overline{\Lambda}$ polarization in different processes are presented in the Figs. 4, 5 and 6. As one can see from the Fig. 4 the existing data [12] does not allow to distinguish between *BGH* and *BJ* mechanisms for the spin transfer. But, as one can see from Figs. 5 and 6 in the current fragmentation region of deep inelastic scattering

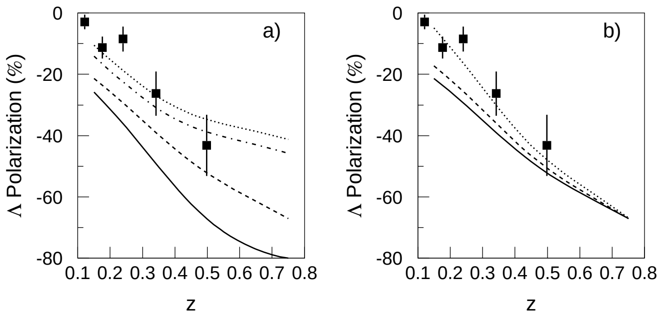


Figure 4: *a)* $\Lambda/\overline{\Lambda}$ *polarization at the* Z^0 *pole for different mechanisms of spin transfer: solid line - NQM, dashed - BGH, dotted - BJ-I, and dot-dashed - BJ-II. The experimental data (full squares) are from [12]. b) comparison between predictions using the BGH model for the* Λ *polarization in our analysis (solid line) and the analysis of [12] assuming that only* s *quarks contribute to* Λ *polarization (dashed), and additionally that only first rank* Λ*'s inherit a fraction of the fragmenting quark polarization (dotted).*

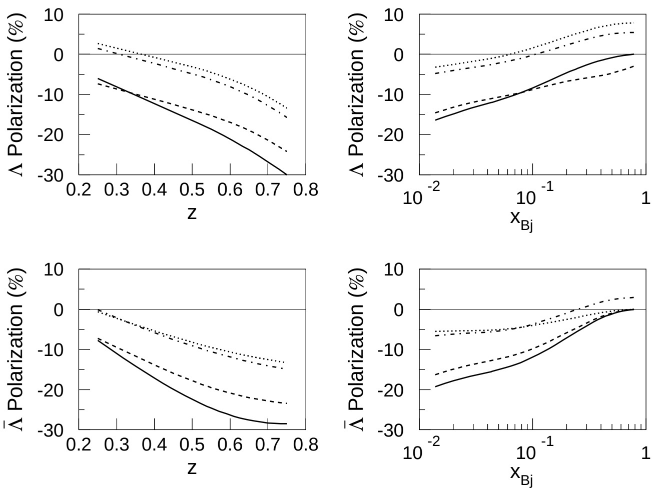


Figure 5: Λ *and* $\overline{\Lambda}$ *longitudinal polarization in the current fragmentation region for DIS of polarized* μ^+*'s on an unpolarized target for different mechanisms of spin transfer: solid line - NQM, dashed - BGH, dotted - BJ-I, and dot-dashed - BJ-II.*

the predicted $\Lambda/\overline{\Lambda}$ polarizations are rather different for the two mechanisms. Our studies have shown that the $\Lambda/\overline{\Lambda}$ polarization in the current fragmentation region of polarized electro-production is less sensitive to the target polarization (in general) and especially to Δs.

The new accurate data which are soon expected from NOMAD [13], HERMES [14] and COMPASS [7] experiments will provide possibility for detailed study of these interesting phenomena.

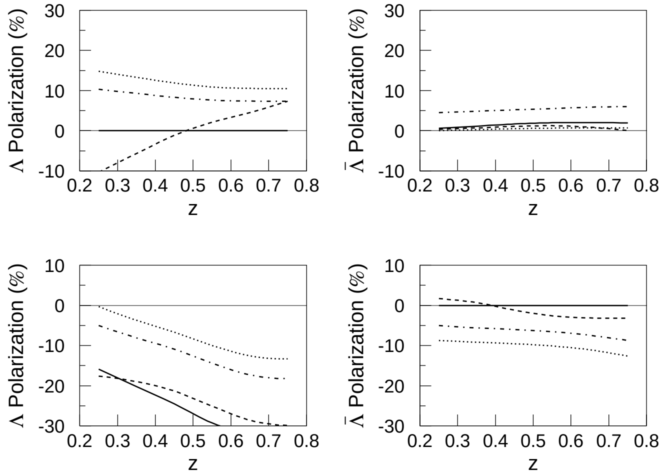


Figure 6: $\Lambda/\overline{\Lambda}$ *polarization in the current fragmentation region in* ν*–DIS (upper plots) and* $\overline{\nu}$*–DIS (lower plots): solid line - NQM, dashed - BGH, dotted - BJ-I, and dot-dashed - BJ-II.*

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